



EFFECTS OF SLOPE ON SOIL LOSS RATE FROM RILL EROSION IN BIU AREA, BORNO STATE, NIGERIA

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ABSTRACT

The study was conducted at six different sites (Piku, Kigir, Dam, Mirnga, Mandaragau and Gunda) in Biu area, under different soil types, topography and vegetation to estimate the soil loss rates on slope due to rill erosion. The study was carried out on annual bases between March and December in 2020. The annual precipitation varied from 699.00 – 896.00mm. and the rainfall erosivity ranged from 351.00 – 485.00 MJmmha⁻¹hr⁻¹yr⁻¹, respectively across the sites. Soil erodibility (0.70 – 0.80) slope length (435.00 – 785.00m), and slope steepness (6 – 9%) cover management factor (0.12 – 0.23) and protection management (0.12), were used as predictor variables in Revised Universal Soil Loss Equation Version 2 (RUSLE2) 2016, across the sites. Six hectares of overland flow sites consisting of rills were selected at random at each site for the study. About 144 soil samples were collected from six sites and RUSLE2 model annual estimation of soil loss was 260.00 – 447.00, respectively. High soil loss was recorded at Piku site with a respective value of 447.00. Based on the result of this study, management of terraces, mulching, cover crops and vegetation, no – tillage method, buffer zones, contour bonds, check dams, grassed water ways and hillside water ponds are recommended to reduce the length of the slope and consequently the soil and water loss.

Keywords: Soil, Erosion, Slope, Steepness, Erosivity, Erodibility,

INTRODUCTION

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel (Wishmeir and Smith, 1978).

Upland or rill-interill erosion is a two-phase process involving detachment and transport of soil particles. Detachment depends on: (a) combined kinetic energy of raindrop, overland flow, and the interaction between raindrop and overland flow, (b) resistance of the soil to the shearing forces listed above, (c) and the resistance or protective effects of crop residue mulch and of the canopy cover. The shearing effects of overland flow are related to its velocity and depth. The velocity of overland flow depends on slope gradient, its depth, and the time of concentration. The latter is a function of slope length. The time of concentration increases with increase in slope length. Consequently, the time available for overland flow to infiltrate into the soil is more on longer than on shorter slope lengths (Lal, 1988).

Slopping farming land accounts for nearly two-third of the total land of the Loess Plateau in China, and the average annual erosive modulus is as high as 25,000 t·km⁻²·a⁻¹ (Gao *et al.*, 2012). This situation makes the Loess Plateau a major source of soil losses, and slope plays a key role in the evolution of eroded soil surface in this loessal region. In order to illustrate the erosion processes, continual scientific efforts have been made to investigate the relationship between slope and erosion, which have been represented by many soil erosions models from the early Zingg from 1940's, to later Smith, Whitt, Musgrave, USLE and WEPP. Some consensus has been arrived at that the slope is an important factor influencing runoff, has a correlation with erosion rate and runoff rate (Fox and Bryann (2000): Ribonzi *et al.*, (2011): El *et al.*, (2013): Shen *et al.*, (2016), influences the duration of time for each stage of erosion (Zhao *et al.*, 2013), and governs soil erosion (Kinnell and Cummings



(1993): Koulouri and Glourga (2007): Assoulieue and Ben (2006); and runoff and erosion tend to increase when a rainfall event occurs on a steeper surface at a critical slope ranging between 5° and 25° (Tang *et al.*, (1998): Mahmordabadi and Sajjadi (2016): Li *et al.*, (2016): Wu *et al.*, (2018).

The micro topographic surfaces are created by using farm tillage tools to form undulating terrains which comprise a mixture of soil grains, aggregates and clods, and whose height variance is rather small (Zheng *et al.*, (2014). When the force of rainfall and runoff causes soil detachment and sediment transport, and creates depressions to store water, the surface roughness changes occur, which have an impact on the evolution of soil erosion, so to throw light on the dynamics of surface micro topography is critically important to understanding erosion (Darboux and Huang (2005): Gomez and Nearing (2005)

As rainfall is the precondition of runoff and soil water erosion, and a hill slope could exacerbate the soil and water loss as gravity aggravates the transportation of the runoff and sediment (Taye *et al.* 2013; Mishra *et al.* 2014; Nourani *et al.* 2015; Larsen *et al.* 2016), therefore, it is essential to understand the effects of the rainfall and slope gradient on the soil and water losses. Rainfall simulation experiments conducted in the arid Sistani region of Iran revealed that the sediment yield was strong at the beginning of the rainfall yet lowered over time when the soil became saturated (Shojaei *et al.* 2020). A field experiment was advanced to investigate the effects of the slope gradient on the surface runoff, runoff coefficient, and sediment yield under natural rainfall conditions, and it was indicated that the runoff responses to rainfall for plots with different slope gradients showed a linear behaviour that significantly increased with the gradient (Jourgholami *et al.* 2021). The objectives of the study are to: - estimate the effects of slope on soil loss, assess the impact of rainfall on soil loss, and state the soil conservation measures necessary to control the soil loss in Biu area.

MATERIALS AND METHODS

The Study Area

The study was conducted in Biu Local Government Area, Borno State, North eastern Nigeria. Six locations; Kigir (10° 35' N, 12° 12' E), Dam (10° 37' N, 12° 9' E), Piku (10° 37' N, 12° 11'E), Mirnga (10° 43'16 N, 12° 8'54 E), Mandaragrau (10°35'52 N, 12° 12'30 E), and Gunda (10°55'N, 11°55'E), were used for the study. Soil sampling was conducted at six stated sites in 2021. In each site, 6 hectares of land were selected at random, (Shipitalo and Edward, 1998). At each site, four (4) land forms (crest, shoulder, back slope and fore slope), were identified and on each land form, one (1) soil sample at 30 cm depth, was collected, making the total of 24 samples, per each site. Since there are six locations (sites) (6 x 24) samples = 144 samples were collected for laboratory analysis. Each soil sample was collected when moist in a well labelled Polyethylene bag. The soil samples were air – dried, sieved through a 2 mm sieve then prepared and analyzed for some physical and chemical parameters that relates to soil erosion. The soil samples were collected at the end of the growing season. The Universal Soil Loss Equation version 2 (RUSLE 2, 2016) was used to calculate the rates of soil loss at each site.

The rainfall was collected using a rain gauge devise for all rainfall events during the study period. The K- factor represents the combined effect of soil texture, organic matter, permeability, and structure on average long term erosion. Cover management factor (C value) was measured by semi detail survey of the crops grown on the field. Support practice factor was measured by semi detail survey of the terraces on the slope. Support practice factor (P) in RUSLE2 is defined as the ratio between soil loss with a specific support practice and the corresponding loss with upslope and down slope tillage.

RUSLE2, Soil Estimation

$$a_i = r_i k_i l S c_i p_i \quad - \quad \text{USDA – ARS, (2016)} \quad (1)$$

Where:

a_i = long – term average soil loss for ith day

r_i = erosivity factor

k_i = soil erodibility factor



- l = slope length factor
S = slope steepness factor
 c_i = cover and management factor

Topographic Factor Estimation

The slope length was measured by GPS tool and slope steepness was calibrated by Theodolite. The effects of topography on soil erosion is accounted for by slope LS factor in RUSLE2, which combines the effect of slope length factor (L) and slope steepness factor (S). Investigation shows that the amount of runoff increases due to the continuous accumulation down the slope as the slope length (L factor) increases, the velocity of the runoff increases as the slope steepness (S) factor) increases. Upon obtaining the L and S values, the topographical factor (LS) values were calculated using the model provided by Wischmeier and Smith (1978) and Kirby (1980).

$$LS = (Length/22.1) m (65.41 \sin^2 \Theta + 4.56 \sin \Theta + 0.065) \quad (2)$$

$$M = 0.6 [1 - \exp (- 35.835 \times S)] \quad (3)$$

$$\Theta = \tan^{-1} (S/100) \quad (4)$$

Where:

L = Field slope (%)

S = Field slope steepness in degree

The variation in value is caused by the variation in the gradient and length of the slope.

Soil Erodibility

The soil erodibility factor (K) of the various sites (Table 2), reveals the resistance of soil to both detachment and transport. Soil erodibility factor (K) ranges from 0.70 – 0.80 across sites. The highest soil erodibility factor was recorded at Dam, Mirnga, Mandaragau and Gunda sites at the range of 0.82 and the lowest value was recorded at Piku and Kigir with their respective value at 0.70. Table 7 reveals soil erodibility factor (K). Dam, Mirnga, Mandaragau and Gunda sites had high soil erodibility than Piku and Mirnga sites. Erodibility defines the resistance of the soil to both detachment and transport

Cover Management Factor

The cover management factor (C – Value) of the study sites (Table 2) in 2020, ranged from 0.12 to 0.23. The highest C – value was recorded at Mirnga followed by Piku and Kigir and then Mandaragau and Dam sites and their values which were recorded at 0.23, 0.14, 0.12, 0.12, and 0.12 respectively. The vegetation varies from grain corn and corn soybean rotation with ridge tillage at all the sites. The vegetation of the various sites varied from guinea corn, bean, and soybean, grain corn with ridge tillage and chisel plow. The C – value is dimensionless with values between 0 and 1 (Molla and Sisheber, 2017).

Protection Management Factor

Table 2 depicts protection and management factor (P – Value) in terms of land used. The study sites ranged within slope percentage of 5 – 10 %, respectively. Piku sites had the highest P – value followed by Kigir, Mirnga, Dam, and Mandaragau. Protection and management factor (P – value), and topography of the study sites showed that Piku (9%) had high slope percentage followed by Kigir (8%) Mirnga (7%) site, Dam, Mandaragau and Mirnga sites recorded the same value of 6%. Also, the P – value of all the sites was 0.12. The P – value reduce the amount and rate of the water runoff, and then reduced the amount of soil erosion. This observation concurs with that of Wischmeier and Smith (1978) that the P factor reflects the practice that will reduce the amount and rate of the water runoff and thus reduce the amount of soil erosion.

RESULTS AND DISCUSSION

Average Annual Precipitation, Rainfall and Runoff Factor and Erosivity Density

Table 1 describes the average annual precipitation, rainfall and runoff factor and erosivity distribution of the various study sites in Biu area. The rainfall data ranges from 2004 – 2011 and 2020 - 2021 for all the sites representing 10years precipitation data. The annual precipitation ranged from (604.80 - 1,045.40 mm) at Kigir and Piku (600.67 – 1001.97 mm), Dam (529.72 – 1050.99mm),



Mirnga (567.56 – 1129.30 mm), Mandaragrau (628.4 – 1108.45mm) and Gunda (534.89 – 1147.80 mm). The average annual precipitation varied from 699.00 – 896.00 mm. The highest annual precipitation was recorded at Dam followed by Kigir, Piku, Mirnga, Gunda and Mandaragrau sites with their respective values at 896.00, 825.89, 810.00, 702.00, 699.00 and 697.00 mm. Higher rainfall intensities across sites in the study area causes high soil loss, this observation agrees with the report of Hudson, (1963) that rainfall intensity of about 25 mmhr⁻¹ was a threshold value, higher intensity than this being erosive.

Table 1: Average annual precipitation, rainfall and runoff factor, and erosivity at various sites in Biu area

Site (mm)	Annual precipitation (mm)	Rainfall and Runoff factor (MJmmha ⁻¹ yr ⁻¹)	Erosivity
Piku	810.00A	512.29C	365.7D
Kigir	825.89A	510.29D	485.00A
Dam	896.00A	514.86B	414.00C
Mirnga	702.00B	535.43A	435.00B
Mand.	697.50B	494.86E	361.00E
Gunda	699.00B	446.57F	351.00F
SE 0.05	23.121	0.1161	0.0387

Source; 2020

SE = Standard error, Mand. = Mandaragrau site

Means followed by the same letter (s) in a column are not significantly different at $p < 0.05$

Effects of Slope on Soil Loss Rates in Biu Area

Table 2 depicts slope length and steepness of the study sites. Kigir recorded the highest slope length of 785.00 m followed by Piku, Mirnga, Dam, Gunda and Mandaragrau sites with their respective values of 713.00, 665.00, 643.00, 508.00 and 435.00 m. Also, Piku recorded the highest steepness followed by Kigir, Mirnga, Dam, Mandaragrau, and Gunda with their respective values at 9.00, 8.00, 7.00 and 6.00. Slope length ranged from moderate to high, while percentage of slope was ranked high in terms of soil loss across sites. Kigir site with high slope length and percentage has high risk of soil erosion than Piku, Mirnga, Dam, Gunda and Mandaragrau sites with shorter length and considerable percentages of slope steepness as a result of volume and velocity of runoff in the sites. Soil erosion occurred in all the sites, because of the percentages of slope steepness were above 5 %. Percentage slope steepness less than 5 % erosion hazard is negligible.

Soil loss rates (Table 3) at Piku, Kigir and Dam sites were higher than Mirnga, Mandaragrau and Gunda sites. This occurred as a result of high rainfall intensity recorded at the stated sites (Table 1). The kinetic energy of raindrop used to be high when the rainfall increased. This observation agrees with the reports of Zambon *et al.*, (2020) and Zhang *et al.*, (2022) that the amount of rainfall on the slope surface per unit time increases with increasing rainfall intensity, the kinetic energy of the raindrops also increased. This phenomenon made the striking raindrops at high rainfall intensities more likely to damage the surface soil structure and loosen the surface soil when compared to the low rainfall intensities, thus increasing the likelihood of soil particles being carried away by the runoff. In addition, with the increase in the rainfall intensity, the runoff volume on steep slopes increased rapidly, which caused erosion and scouring on the soil to be more significant than that at low rainfall intensity. Eventually these effects lead to an increase in the sediment's loss.

As rainfall is the precondition of runoff and soil water erosion, and a hill slope could exacerbate the soil and water loss as gravity aggravates the transportation of the runoff and sediment (Taye *et al.* 2013; Mishra *et al.* 2014; Nourani *et al.* 2015; Larsen *et al.* 2016), therefore, it is essential to understand the effects of the rainfall and slope gradient on the soil and water losses in a purple soil area. In recent decades, researchers have paid significant attention to the influences of rainfall and topographic conditions on the soil and water loss (Maltsev &Yer-molaev 2019; Belayneh *et al.* 2020; Zhang *et al.* 2021).



Effects of slope length on runoff per unit area are not clearly defined. Other factors remaining the same, runoff per unit area may decrease with increase in slope length (Lai, 1983). In contrast, Laflen & Saveson (1970) reported that runoff increased linearly with an increase in the ratio slope steepness: slope length. Wischmeier (1966) and Wischmeier & Smith (1978) reported either negligible effects of slope length on annual runoff per unit area of cropland, or slightly lower runoff on the longer slopes during the growing seasons and slightly higher during the dormant season. The effects of slope length on soil erosion are confounded by slope gradient, slope shape, and slope-induced alterations in soil properties. Other factors remaining the same, soil erosion supposedly increases in proportion to some power of slope length. Higher erosion on longer slopes may be due to increased runoff velocity on longer slope lengths and therefore, due to increase in rill erosion (Foster *et al*, 1977).

Table 2: Soil erodibility factor, slope length and steepness, C and P values of the various study sites in Biu area

Study sites	Soil erodibility (k)	Slope len.	Slope %	C – Value	P value
Piku	0.70B	713.00B	9.00A	0.14C	0.12
Kigir	0.70B	785.00A	8.00B	0.14C	0.12
Dam	0.82A	643.00D	6.00D	0.12D	0.12
Mirnga	0.82A	665.00C	7.00C	0.23A	0.12
Mandaragrau	0.82A	435.00F	6.00D	0.12D	0.12
Gunda	0.82A	508.00E	6.00D	0.12D	0.12
SE _{0.05}	4.869	2.556	0.064	3.776	

Source: 2020

Key: SE = Standard error, Mand. = Mandaragrau site, C – values = cover and management factor, P – value = protection and management factor, Slope len. = slope length, Slope % = slope steepness.

Means followed by the same letter (s) in a column are not significantly different at $p < 0.05$

Table 3: Annual soil loss estimated by empirical and RUSLE2 models ($\text{Kg ha}^{-1}\text{yr}^{-1}$), in 2020.

Study Site	Measured model	RUSLE2 model
Piku	337.39A	447.00A
Kigir	224.71C	330.00B
Dam	227.58B	308.00C
Mirnga	168.38F	269.00E
Mandaragrau	193.49D	292.00D
Gunda	184.88E	260.29F
SE _{0.05}	0.107	0.108

Source: 2020

Key: SE = Standard error.

Mean followed by the same letter (s) in column are not significantly different at $p < 0.05$

CONCLUSION AND RECOMMENDATION

The extent of rill erosion was quantified using empirical and RUSLE2 models prediction techniques under same condition of Biu environment. RUSLE2 estimates rates of rill and interrill soil erosion was caused by rainfall and its associated overland flow. The pattern, rate and estimates of soil losses were confined to rainfall amount as the season progressed to a peak in the month of July and therefore decline with cessation of rainfall in October in the study area. Soil loss was significantly ($p < 0.05$) higher at Piku followed by Kigir, Mirnga, Mandaragrau, Gunda and Dam in this study. RUSLE2 model gave high prediction accuracies of soil loss, while the empirical model had moderate accuracies in terms of soil loss prediction in the study sites. However, both models showed low to high prediction strength at locational bases. On aggregate basis RUSLE2 model surpassed with greater strength of prediction accuracy than empirical model.



Concerning management strategies to reduce soil losses, intervention will focus on the slope length and steepness, conservation management factor and support practice factor as the erodibility and runoff factor cannot be changed. Based on the result of this study, the recommendations were made:

i. Mulching; - mulch is any layer of material applied to the surface of the soil to protect the soil from the erosion and evaporative effects of wind and sun. Mulch can be plant material, like straw and wood chips or it can be gravel or non – living material like recycled glass, cinders, decorative rock and recycled rubber.

ii. Cover Crops and Vegetation; - cover crops increases soil health improves soil structure and reduces the need for costly inputs such as fertilizer and mechanical tillage. Cover crops protect water quality by slowing erosion and runoff and increases water infiltration and retention.

iii. No tillage method; - in zero tillage, the land for crop cultivation is left undisturbed from harvest to planting or not ploughed at all while in the case of minimum tillage, just holes for planting are made and only at the places where the crop is going to be planted or grain sown. A combination of no tillage with crop residue mulch is more effective in runoff and erosion control

iv. Buffer Zones; - buffer zone increases the capture of sediments and organic materials. It is revealed that buffer zone increase the trapping of sediments and infiltration from 10 to 90 %. Vegetative buffers decrease the runoff velocity of water.

v. Terraces; - terraces are mechanical structures such as an earthen ridge or stone wall which reduces the slope steepness and divides the slope into short gentle sloping sections. Terraces reduces the runoff velocity and soil loss, increases the soil moisture content through improve infiltration, reduce evaporation and can be created to divert runoff to a prepared or safe area for minimizing the effect of soil erosion to a tolerable level.

vi. Contour Bunds; - as progressive terraces, contour bunds are suited to flat areas of slope less than 16 %. Contour bunds can reduce the soil erosion and increase the soil water holding capacity in the intervention area.

vii. Check Dam; - check dams are structures constructed across a channel or a river to lesson water velocity and to catch sediments.

viii. Anti – erosive ditches; -an anti – erosive channel is a drainage channel constructed to prevent runoff water from upper hill to enter a cropped land. In this channel, water may infiltrate or may be diverted.

ix. Grassed waterways; - grassed waterways are more important in filtering by retaining runoff sediments, pollutants and other particulate matter within storm water and their performance will depend on soil permeability within the area.

x. Hill side water ponds; - rain water harvesting is a system of collecting water through different technologies such as storage of rain water on surface reservoirs and ground water recharge for future use. The use of ponds for retaining water reduces soil erosion.

xi. Retaining walls made of gabions for slope stabilization; - retaining walls are structures made of masonry, stone, brick, concrete or combination of these. They are used as erosion control structures. Comparatively to other retaining walls, the main advantage of gabions retaining walls is to reduce the runoff velocity or to increase the stability of sloping surface area with seepage problems.

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